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MEMORANDUM REPORT ARBRL-MR-02926

EROSIVITY OF A NITRAMINE PROPELLANT WITH A FLAME TEMPERATURE COMPARABLE TO M30 PROPELLANT

J. Richard Ward
Robert W. Geene

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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The erosivity of a nitramine propellant with a flame temperature comparable to M30 was measured in a 37mm blowout chamber. The nitramine propellant had the same erosion rate as M30, 2.4 vs 2.3 mg/shot, respectively, at a charge mass of 63 g, respectively, and a rupture pressure of 248 MPa.

This is the second example of a nitramine propellant that is no more erosive than conventional propellants, contrary to previous Army results. The adiabatic flame temperatures of the two nitramine propellants tested range from 2949K to 3255K.

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I. INTRODUCTION

For some guns, propelling charges can be made from propellants with different adiabatic flame temperatures by appropriately adjusting charge weight and web size. Experience dictates that the erosivity of such propelling charges with the same internal ballistics is proportional to the propellant's adiabatic flame temperature[1]. The charge designer should strive to use the propellant with the lowest flame temperature.

Propellants made with RDX or HMX have lower flame temperatures at a given impetus than do double-base, nitrocellulose-nitroglycerine (NC-NG) propellants, or triple-base, nitrocellulose-nitroglycerine-nitroguanidine (NQ) propellants. The RDX and HMX propellants, denoted nitramine propellants, ought to be less erosive than conventional propellants. The wear life of a gun barrel could be increased with a nitramine propellant that has the same impetus as the standard propellant but with a correspondingly lower flame temperature. Alternately, one could increase the muzzle velocity of a gun without aggravating the erosion rate using a higher impetus nitramine propellant with a flame temperature comparable to the standard propellant.

Prior experiments in the US concluded that nitramine propellants exhibited higher wear rates than conventional propellants[2-4]. To verify this anomaly for the nitramine propellants, the erosion rate was measured for a nitramine propellant with a flame temperature of 3250K and an impetus corresponding to an NC-NG propellant with a flame temperature of 3800K[5]. The experiment concluded that the wear rate with the nitramine propellant was less than the wear rate with the NC-NG propellant with the same flame temperature.

These results have prompted programs to formulate nitramine propellants to replace triple-base M30-series propellants, the propellants in the top-zone of the four, fielded, wear-limited Army cannons (105mm M68, 155mm M185 and M199, and the 8-inch M201). In this report,

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1. *J.R. Ward, "A New Initiative in Gun Barrel Wear and Erosion", Proceedings of the Tri-Service Gun Barrel Erosion Symposium, Dover, NJ, March 1977.*
2. *"Hypervelocity Guns and the Control of Gun Erosion", Summary Technical Report of Division I, NDRC, Vol. I, 1946.*
3. *J.P. Picard and R.L. Trask, "The Effect of Propellant Ingredient Functional Groups on Gun Barrel Erosion and a Search for More Effective Additives for Reducing Erosion", Proceedings of the International Symposium on Gun Propellants, Picatinny Arsenal, October 1973.*
4. *E.F. Bozza, B. A. Lehman, and R.P. Baumann, "High-Force, Low-Flame Temperature, Nitramine Filled Propellants", ibid.*
5. *R.W. Geene, J. R. Ward, T.L. Brosseau, A. Niiler, R. Birkmire, and J.J. Rocchio, "Erosivity of a Nitramine Propellant", Proceedings of the 1978 JANNAF Propulsion Meeting, CPIA, February 1978.*

the erosivity of a nitramine propellant with a flame temperature comparable to M30 was measured in the 37mm blowout chamber. The results from this test series are also analyzed with the earlier experiments to compare nitramine propellant erosivity with standard Army propellants.

II. EXPERIMENTAL

The erosion experiments were conducted in the blowout chamber, depicted in Figure 1, which was made from the breech and chamber of a 37mm gun. A steel nozzle made with AISI 4140 gun steel sits at the mouth of the cartridge case. Mild-steel shear disks are placed downstream of the nozzle. The shear disks are held against the back of the nozzle with a steel spacer which also has a rubber O-ring seal. This erosion apparatus has been in use at the Ballistic Research Laboratory (BRL) since the Second World War. Most of the early experiments at BRL did not use the shear disks, since experiments were designed to simulate erosion over recoilless-rifle nozzles[6-15]. The shear disks have been used exclusively with later erosion experiments within the Laboratory[5,14,15].

The nozzle is shown in Figure 2. This nozzle shape evolved from the early BRL experiments wherein the nozzle was cylindrical at the commencement of testing, but gradually eroded to the shape in Figure 2.

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6. *J.H. Wiegand, "Erosion in Vent Plugs", BRL Report No. 520, January 1945.*
7. *J.H. Wiegand, "Erosion in Vent Plugs-II", BRL Report No. 578, January 1946.*
8. *S. Breitbart, "On Erosion of Dry Pressed Ceramic Materials by Powder Gases", BRL Memorandum Report No. 483, September 1949.*
9. *S. Breitbart, "On Erosion of Hot Pressed Ceramic Materials by Powder Gases", BRL Memorandum Report No. 498, October 1949.*
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14. *A. Niiler, J.E. Youngblood, S.E. Caldwell, and T.J. Rock, "An Accelerator Technique for the Study of Ballistic Surfaces", BRL Report No. 1815, August 1975.* (AD #A016899)
15. *M.A. Schroeder and M. Inatome, "The Relationship Between Chemical Composition and Wear-Reducing Effectiveness of Some Laminar Additives for Gun Propellants: Polyvinyltetrazole", BRL Memorandum Report No. 2512, August 1975.* (AD #B007029L)

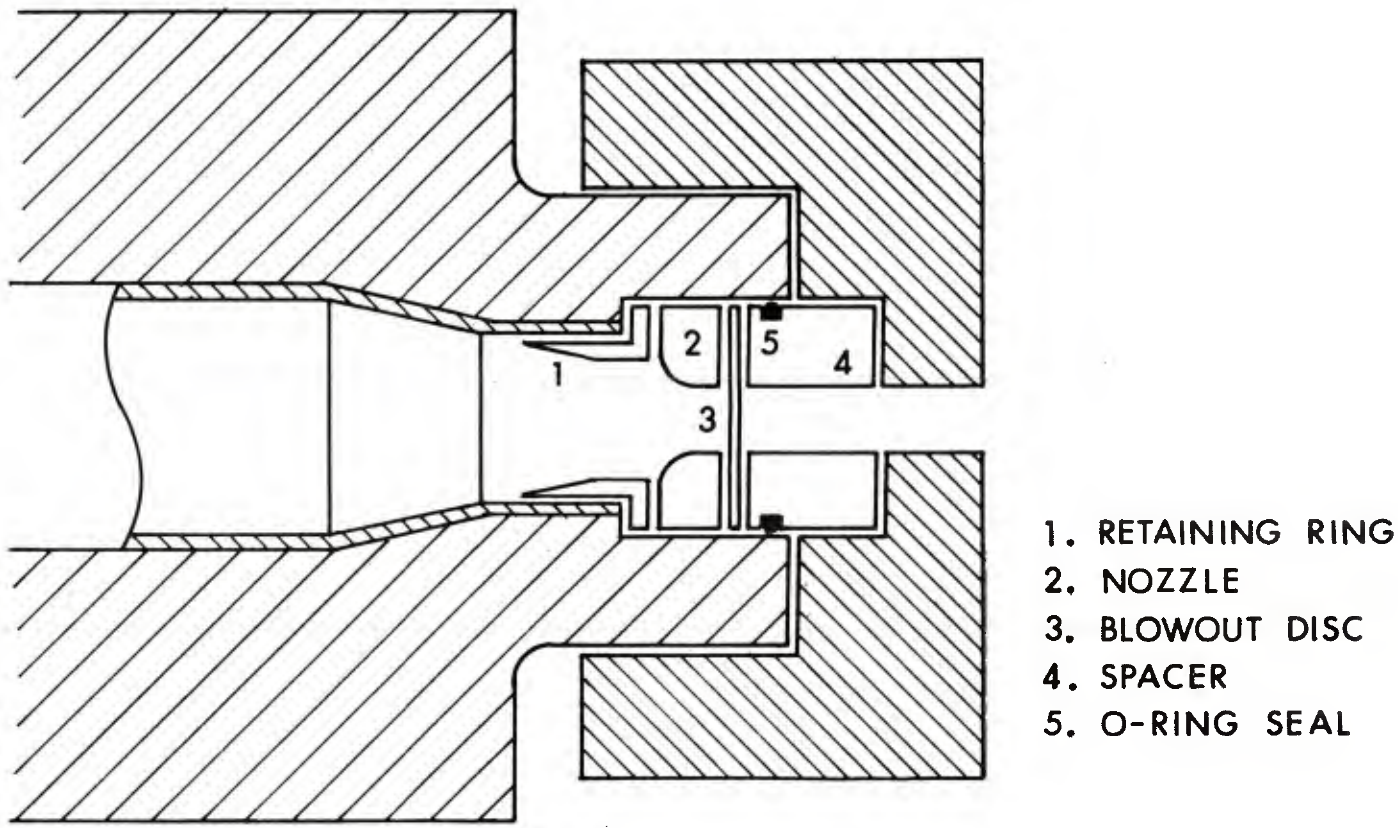

Figure 1. 37mm Vented Chamber.

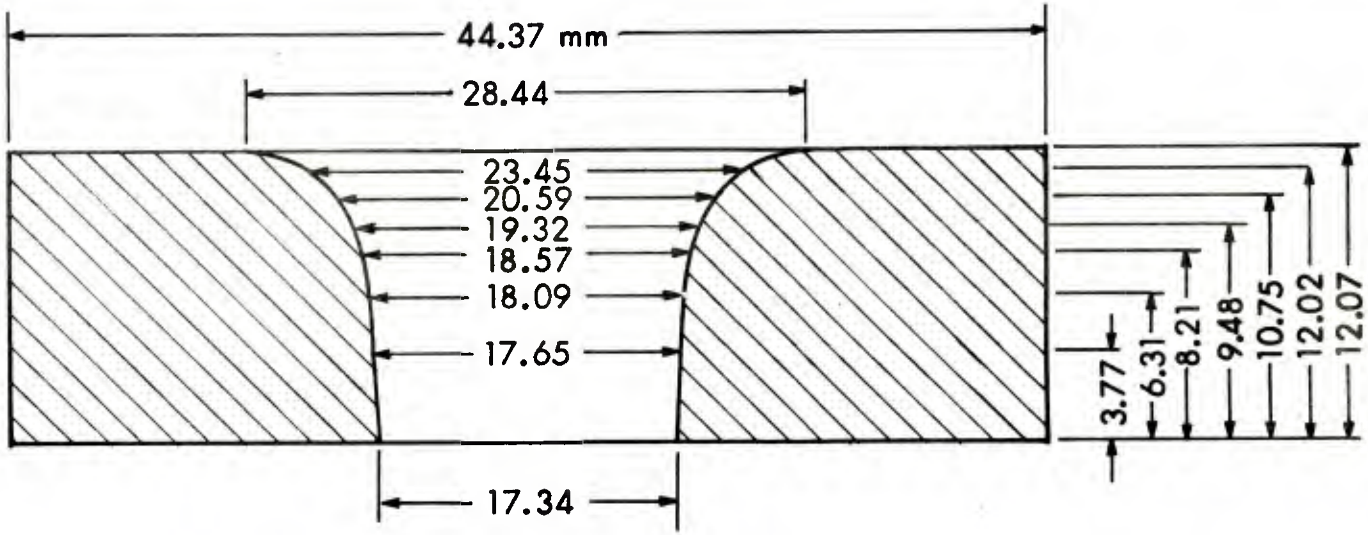

Figure 2. Nozzle Dimensions.

The mass loss/shot was, therefore, higher than the mass loss/shot measured after the nozzle assumed the shape in Figure 2. Thereafter, mass loss/shot was reproducible.

Following each shot, the steel nozzle was cleaned with soap and water, dried, and weighed on a Sartorius Model 2462 microbalance which has a sensitivity of 0.1 mg.

The pressure in the blowout chamber was measured with a BRL Minihat gage.

The propellants were ignited with an M1B1A2 percussion primer containing 6.5 g of black powder.

The chemical compositions, dimensions, and thermochemical properties of the nitramine propellant and the other propellants evaluated in the previous nitramine erosion study are listed in Table I. The inclusion of M8, M1, and the high-force nitramine propellant denoted HFP was made to facilitate discussion of the present test results with the results in reference 5.

Initial firings were performed with M5 propellant to insure proper functioning of the equipment prior to firing the nitramine propellant of which there was a limited supply.

III. RESULTS

Figures 3 and 4 depict the chamber pressure-time curve for M5, M30, and the nitramine propellant. The results from the firings are listed in Table II. The mean mass loss/shot and standard deviation are presented in Table III. By inspection, one sees that the mass losses are equivalent for NT-6396 and M30 which means NT-6396 could be substituted for M30 with no great increase in barrel wear expected. The percent increase in muzzle velocity that can be achieved by substituting NT-6396 for M30 is approximately equal to the square root of the ratio of the propellant impetus[16]. From the values in Table I, this translates to a 1.5 percent increase in muzzle velocity by replacing M30 with NT-6396. Such an increase in muzzle velocity could be important in tank cannon firing high-velocity, low-drag, armor-piercing penetrators where a small change in muzzle velocity can significantly increase the penetrator's effective range.

In order to see how the results from this test series complement data taken in the first nitramine tests, Table IV summarizes all the data acquired. The main conclusion is that the two nitramine propellants are no more erosive than standard propellants. Compared with double-

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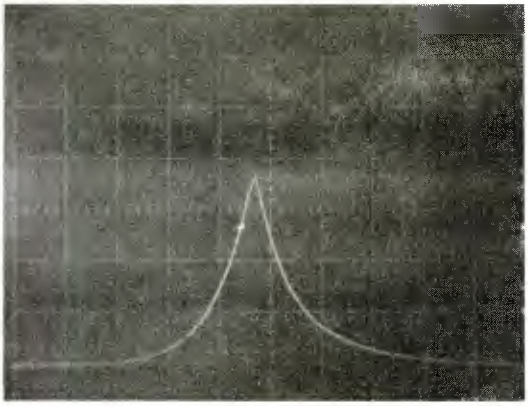
16. J. Corner, Theory of the Interior Ballistics of Guns, New York, Wiley and Sons, Inc., 1950.

TABLE I. Compositions, Thermochemical Properties, and Grain Dimensions of Propellants Fired in the Nitramine Erosion Tests

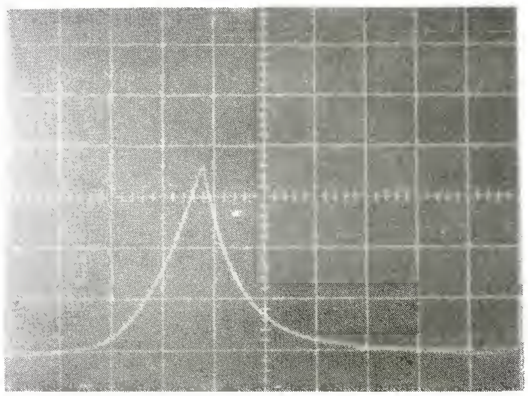
	NT PPL-A-6396	M30 PPL-A-6372	HFP PPL-A-6380
Nitrocellulose (12.6%N)	28.5%	28.0%	29.3%
Nitroglycerin	20.5	22.5	22.7
Nitroguanidine	7.0	47.7	5.0
RDX	34.5		36.5
Dioctylphthalate	8.0		5.0
Ethyl Centralite	1.5	1.5	1.5
Cryolite		0.3	
Total Volatiles (Residual)	(0.3)	(0.2)	(0.3)
Impetus (MJ/kg)	1.120	1.088	1.179
Flame Temperature (K)	2949.	3040.	3255.
Covolume (m^3/kg)	1.10×10^{-3}	1.057×10^{-3}	1.069×10^{-3}
Ratio of Specific Heats	1.236	1.238	1.243
Molecular Wt. Gases	21.89	23.21	23.08
Grain Length (mm)	10.46	7.78	10.58
Grain Diameter (mm)	2.48	1.59	2.37
Grain Perf. Diameter (mm)	0.83	0.46	0.77
Grain Web (mm)	0.83	0.56	0.80
Grain Geometry	SP	SP	SP

TABLE I. Compositions, Thermochemical Properties, and Grain Dimensions of Propellants Fired in the Nitramine Erosion Tests (Cont'd)

	M5	M8	M1
Nitrocellulose	81.95%	52.15%	85.00%
(Percent Nitrogen)	(13.25)	(13.25)	(13.25)
Nitroglycerin	15.00	43.00	
Ethyl Centralite	0.60	0.60	
Barium Nitrate	1.40		
Potassium Nitrate	0.75	1.25	
Diethylphthalate		3.00	
Dinitrotoluene			10.00
Dibutylphthalate			5.00
Diphenylamine (Added)			(1.00)
Ethyl Alcohol (Residual)	(2.30)	(0.40)	(0.75)
Water (Residual)	(0.70)		(0.50)
Graphite	0.30		
Impetus (MJ/kg)	1.061	1.142	0.912
Flame Temperature (K)	3245.	3695.	2417.
Covolume (m^3/kg)	0.994×10^{-3}	0.962×10^{-3}	1.104×10^{-3}
Ratio of Specific Heats	1.226	1.215	1.259
Molecular Wt. Gases	25.41	26.95	22.06
Grain Length (mm)	10.58	(25.4)	8.26
Grain Diameter (mm)	3.92	(12.7)	3.68
Grain Perf. Diameter (mm)	0.41		0.37
Grain Web (mm)	0.69	0.56	0.64
Grain Geometry	7 Perf	Strip	7 Perf

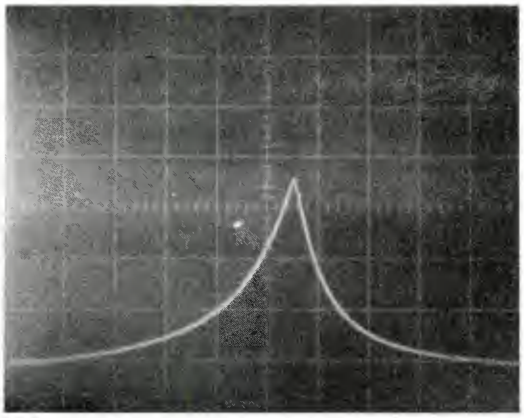


M5 (Round 11)



M30 (Round 17)

Figure 3. Sample Pressure-Time Curves. Y-Axis Units 69 MPa/Division; X-Axis 2 ms/Division.



NT-6396 (Round 32)

Figure 4. Sample Pressure-Time Curve. Y-Axis Units 69 MPa/Division; X-Axis 2 ms/Division.

TABLE II. Mass Loss of Nozzle 31 *vs* Shot Number at 248 MPa Rupture Pressure

Test Shot Number	Propellant	Propellant Mass, g	Mass Loss, mg
11	M5	68	8.6
13	M5	68	6.9
15	M5	68	9.0
17	M30	65	1.9
18	M30	65	1.5
19	M30	65	2.8
20	M30	65	1.9
21	M30	65	2.0
22	NT-6396	65	3.6
23	NT-6396	63	1.4
24	NT-6396	63	3.6
25	NT-6396	63	1.3
26	NT-6396	63	2.1
32	NT-6396	63	1.3
33	NT-6396	63	2.7
34	NT-6396	63	2.6
35	NT-6396	63	2.9
36	NT-6396	63	2.2
37	M30	65	2.7
38	M30	65	3.1

TABLE III. Summary of Mass Loss Measurements on Nozzle 31

Propellant	Number of Shots	Propellant Mass, g	Mean Mass Loss[a], mg/shot
M5	3	68	8.2 ± 1.1
M30	7	65	2.3 ± 0.6
NT-6396	10	63[b]	2.4 ± 0.9

[a] *One standard deviation from the mean.*
[b] *One shot had 65g mass.*

TABLE IV. Summary of Mass Loss/Shot for the Propellants Tested in the Nitramine Propellant Erosivity Program

Propellant	T°,K[a]	Mass, g	Rupture Pressure, MPa	Mean Mass Loss, mg/shot	Number of Shots
M1	2417	70	193	1.5 ± 0.6	12
M1	2417	70	193	0.8 ± 0.3	8
M1	2417	86	283	0.8 ± 1.0	3
M30	3040	58	193	2.9 ± 0.9	12
M30	3040	65	248	2.3 ± 0.6	7
M30	3040	75	283	3.5 ± 1.3	3
M30	3040	100	413	23.8	1
NT-6396	2949	63	248	2.4 ± 0.9	10
M5	3245	60	193	5.0 ± 1.7	12
M5	3245	60	193	5.2 ± 0.8	6
M5	3245	60	193	4.0 ± 0.4	4
M5	3245	68	248	8.2 ± 1.1	3
M5	3245	77	283	25.9 ± 0.9	2
M5	3245	100	413	116.4	1

[a] *Propellant Flame Temperature*

TABLE IV. Summary of Mass Loss/Shot for the Propellants Tested in the Nitramine Propellant Erosivity Program (Cont'd)

Propellant	T°,K[a]	Mass, g	Rupture Pressure, MPa	Mean Mass Loss, mg/shot	Number of Shots
HFP	3255	54	193	3.1 ± 1.0	3
HFP	3255	70	283	7.1 ± 0.2	1
HFP	3255	90	413	42.9	1
M8	3695	54	193	17.7 ± 4.2	12
M8	3695	69	283	60.8 ± 12	3
M8	3695	100	413	306.5	1

[a] *Propellant Flame Temperature*

base propellants, the nitramine propellants appear much less erosive for a given flame temperature.

To illustrate trends and to see how the nitramine propellants fit into such trends, Figures 5-9 were constructed in which mass loss/shot was plotted against rupture pressure. Smooth curves were drawn through the data points. One sees the mass loss/shot increases at higher rupture pressures and propellant mass.

Figures 5-9 for the individual propellants also serve to show the precision of the erosion of steel by the combustion gases. The standard deviation of the mean for the propellants in which at least ten shots were fired is tabulated with the corresponding mean mass losses in Table V. One sees the standard deviations are all in excess of twenty percent of the mean mass loss/shot.

TABLE V. Standard Deviation of Mass Loss Measurements

Propellant	Number of Shots	Mean Mass Loss, mg/shot	Std. Deviation mg/shot	Percent
M1	12	1.5	0.6	40
M30	12	2.9	0.9	31
NT-6396	10	2.4	0.9	38
M5	12	5.0	1.7	34
HFP	12	3.1	1.0	32
M8	12	17.7	4.2	24

This level of precision must be kept in mind when comparing relative propellant erosivity. For example, the mass loss/shot of M30 was higher at 193 MPa than 248 MPa. In Figure 6, it appears this discrepancy is caused by the precision of the experiment. When one uses the smooth curve drawn through all the M30 data, one sees that the erosivity of M30 at 193 MPa is less than that for HFP at 193 MPa. The seemingly high wear rate for M30 at 193 MPa may have suggested that HFP was no more erosive than M30, a surprising conclusion since the flame temperatures of HFP is higher than M30. Using the smooth curves drawn through the mass losses at each rupture pressure, one would expect from Figure 16 that HFP is more erosive than M30.

Another view of the data in Table IV is provided in Figures 10-13 in which mass loss/shot is plotted against adiabatic flame temperature at each rupture pressure. One sees the propellant erosivity increasing exponentially with flame temperature.

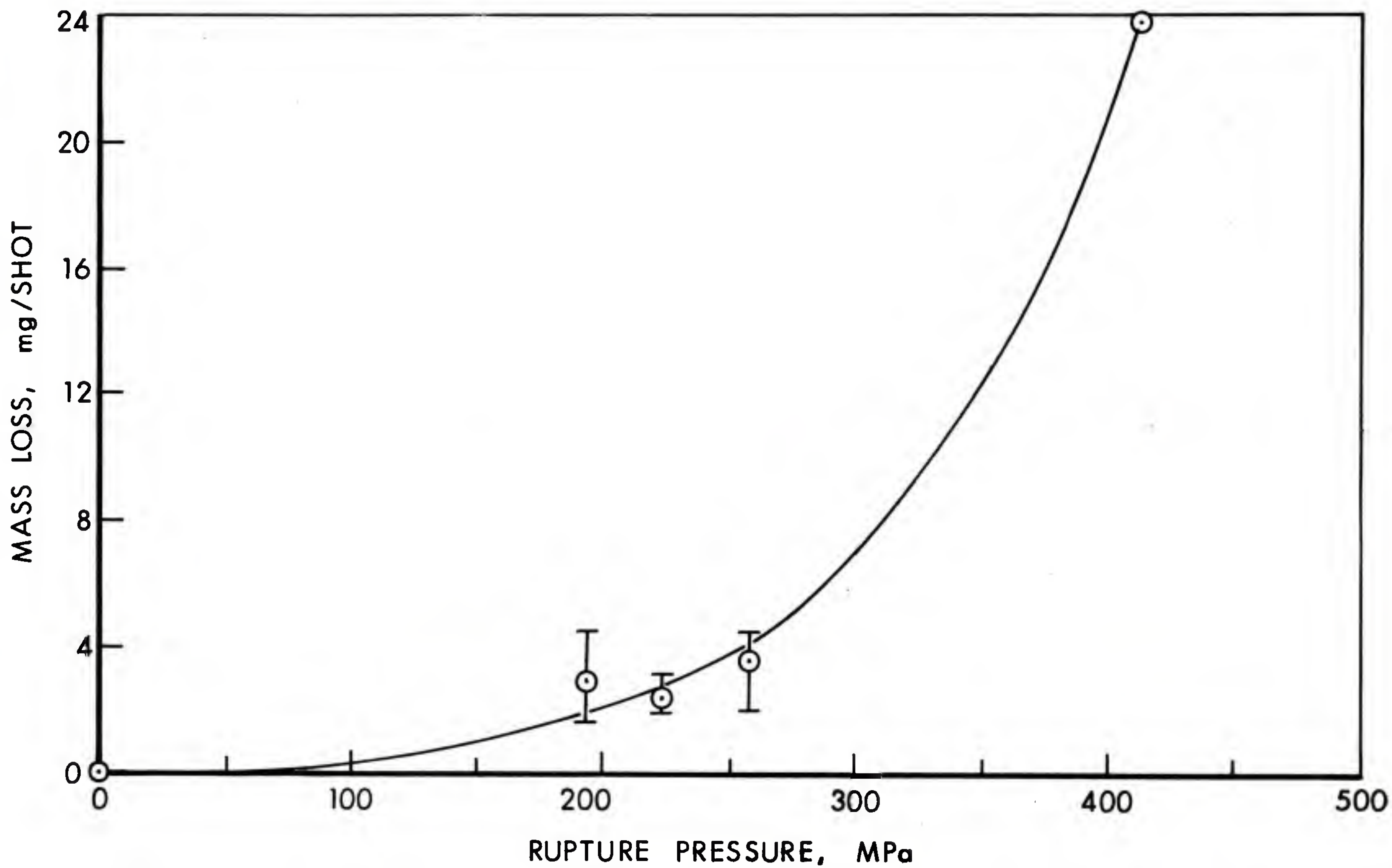


Figure 5. Mass Loss vs Rupture Pressure for M30 Propellant.

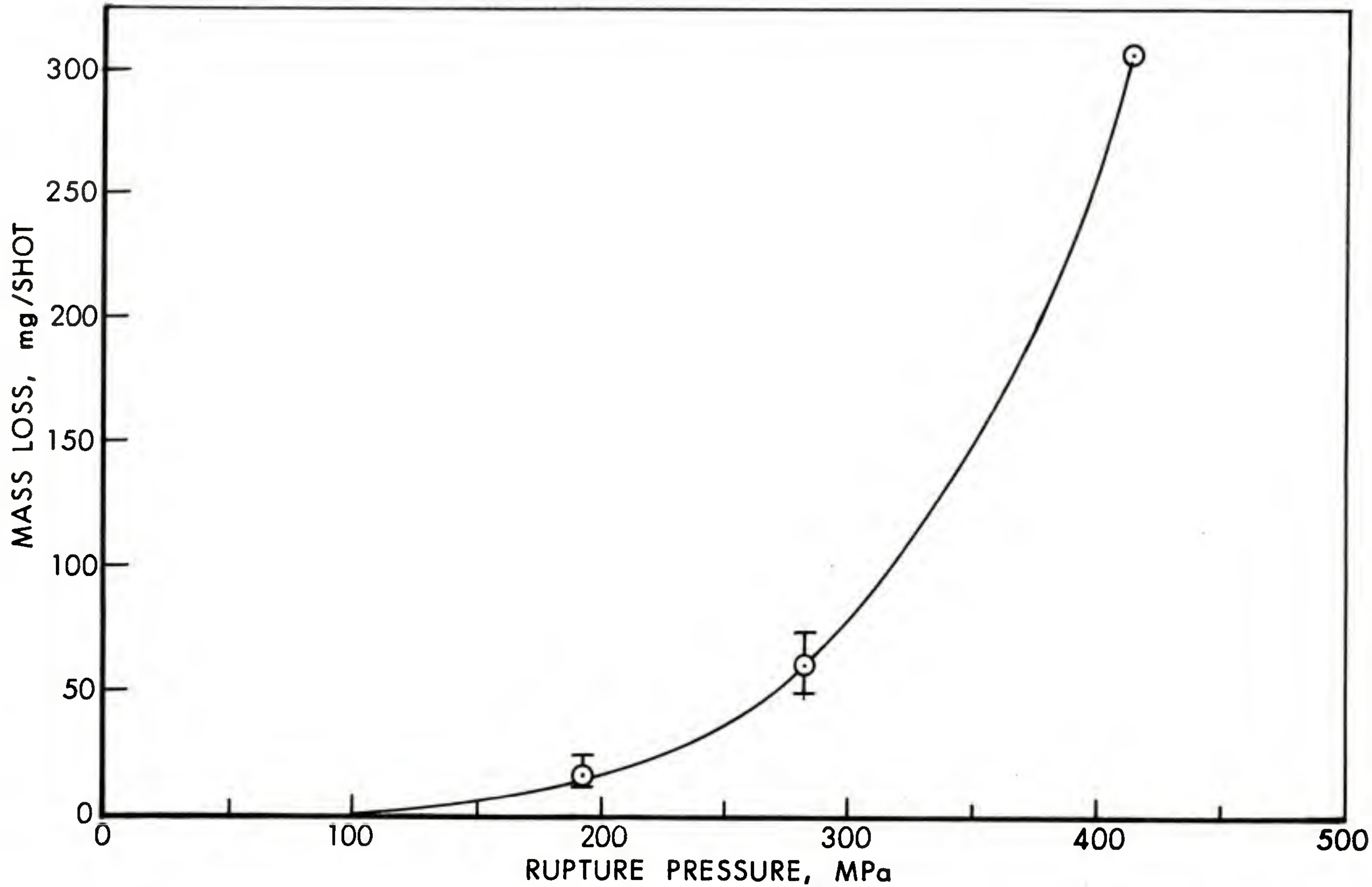


Figure 6. Mass Loss vs Rupture Pressure for ~~HEP~~ M8 Propellant.

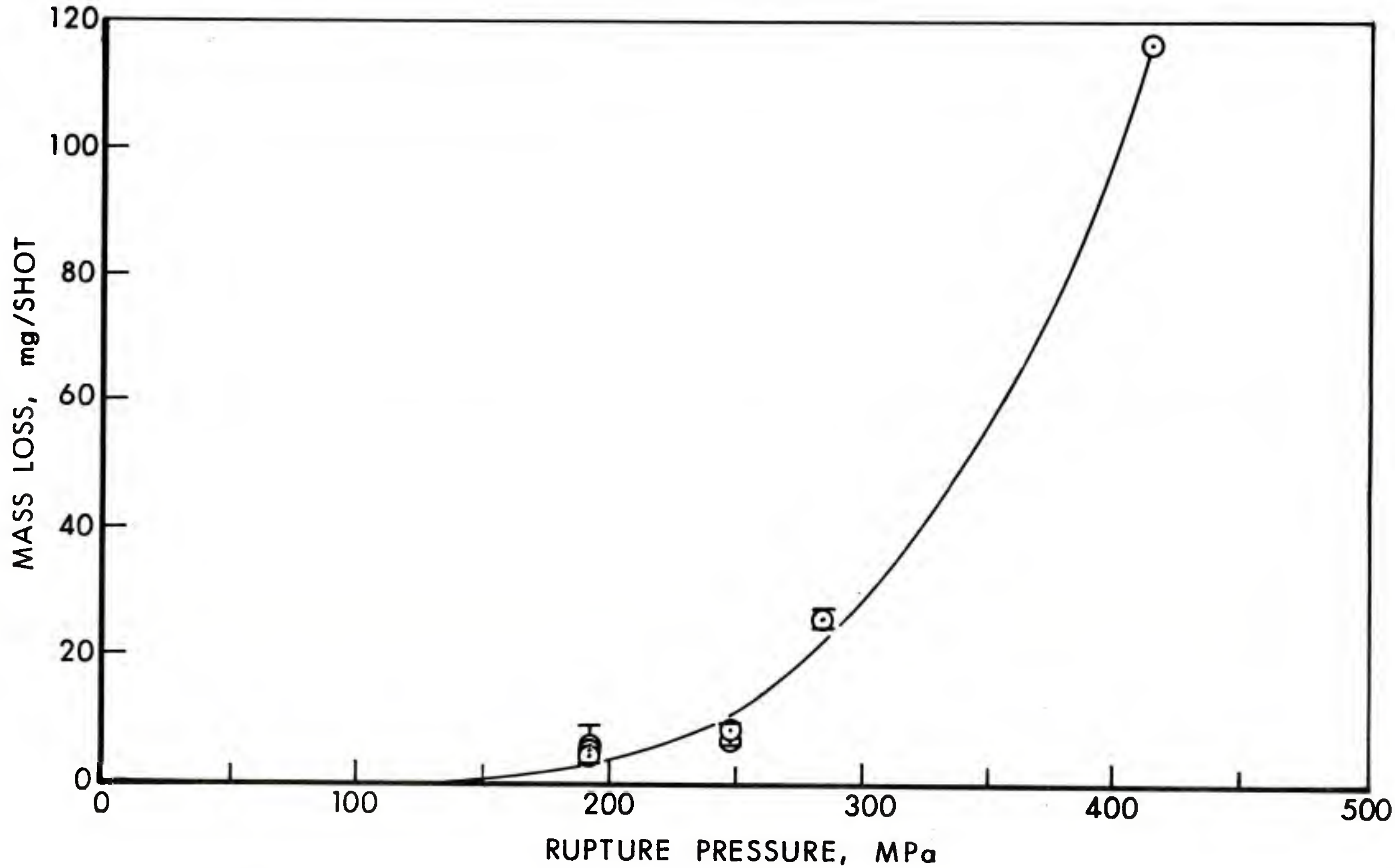


Figure 7. Mass Loss vs Rupture Pressure for M5 Propellant.

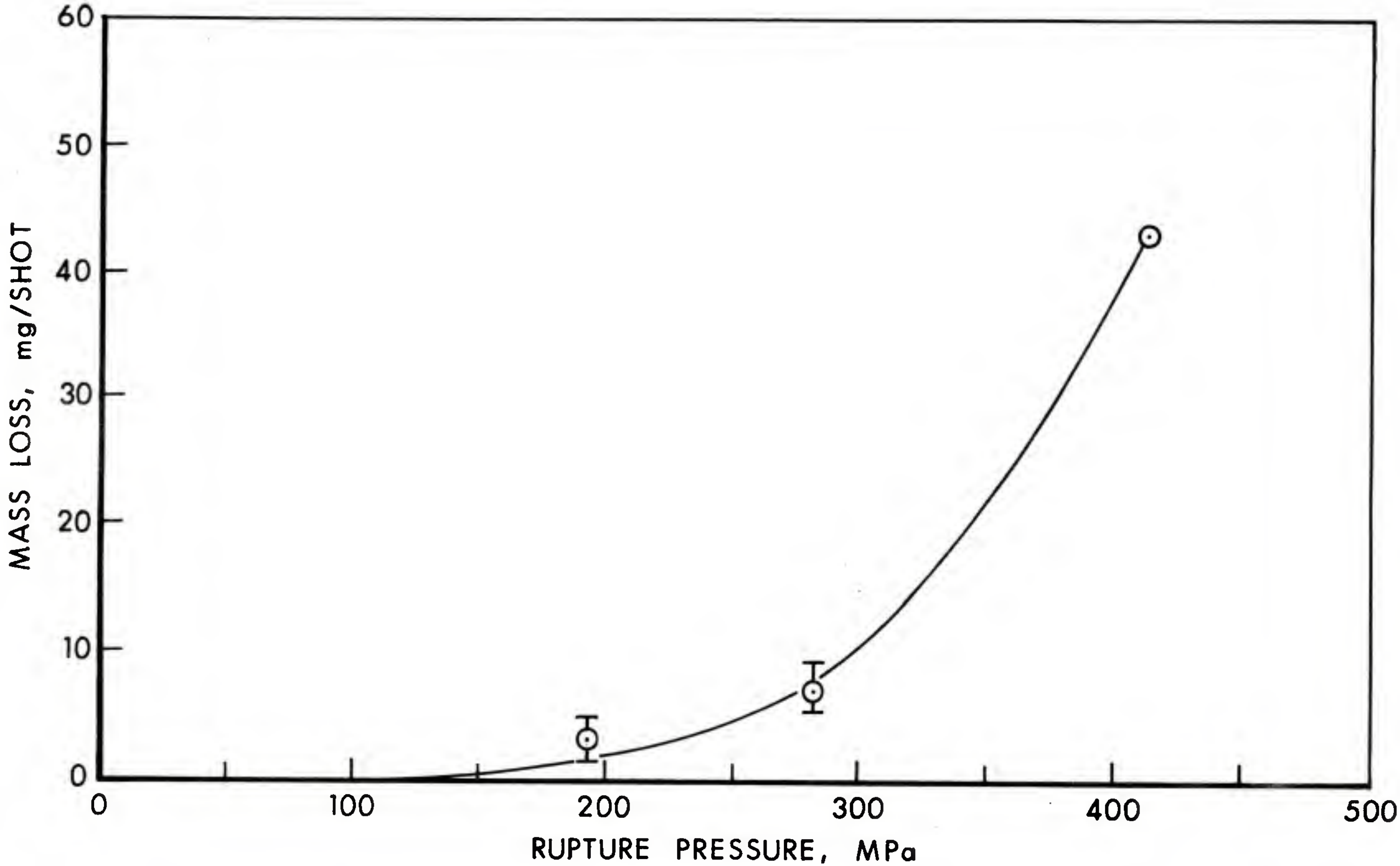


Figure 8. Mass Loss vs Rupture Pressure for ~~M8~~ HFP Propellant.

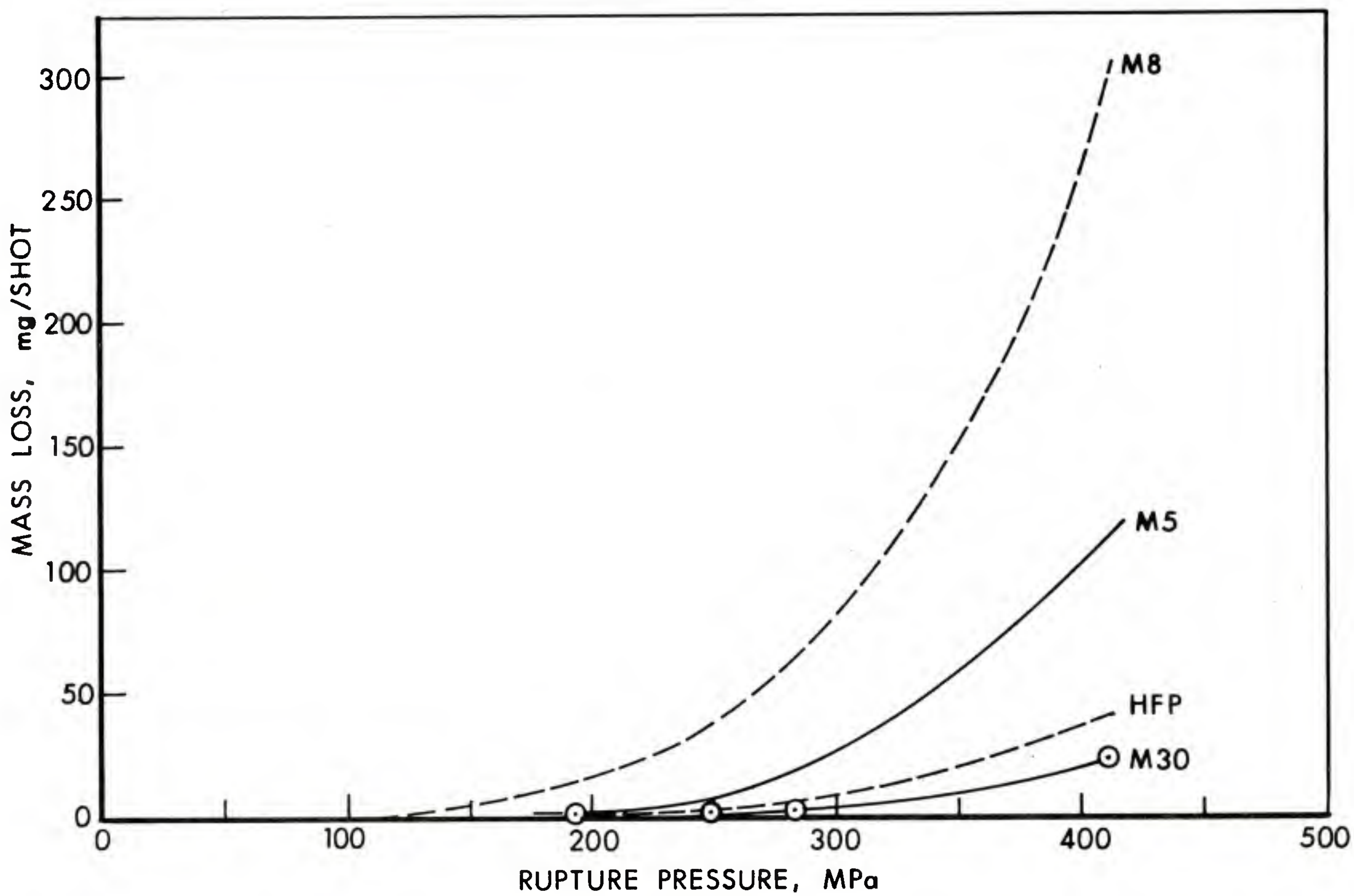


Figure 9. Mass Loss vs Rupture Pressure for the Four Propellants Tested.

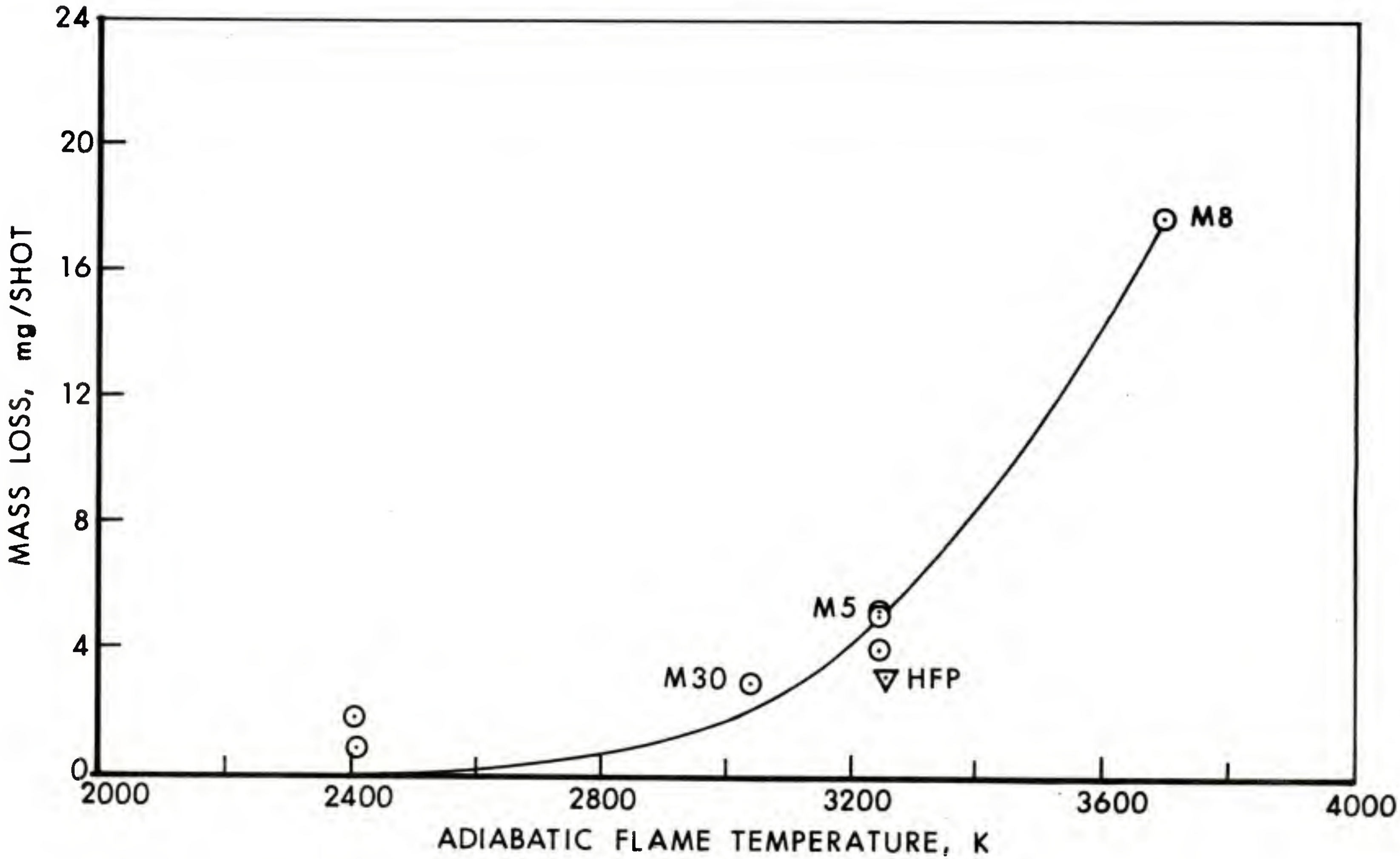


Figure 10. Mass Loss vs Adiabatic Flame Temperature at 193 MPa Rupture Pressure.

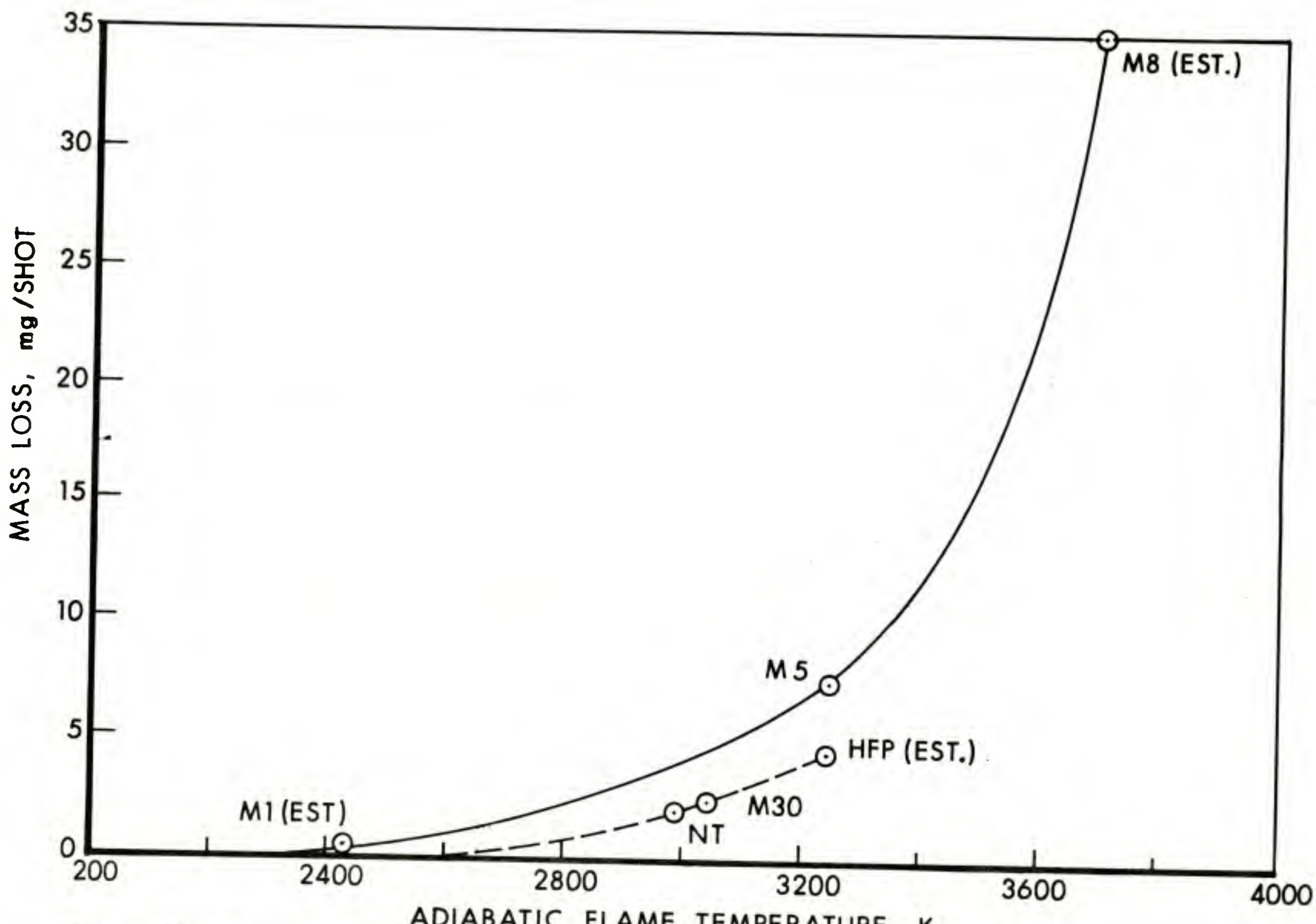


Figure 11. Mass Loss vs Adiabatic Flame Temperature at 248 MPa Rupture Pressure.

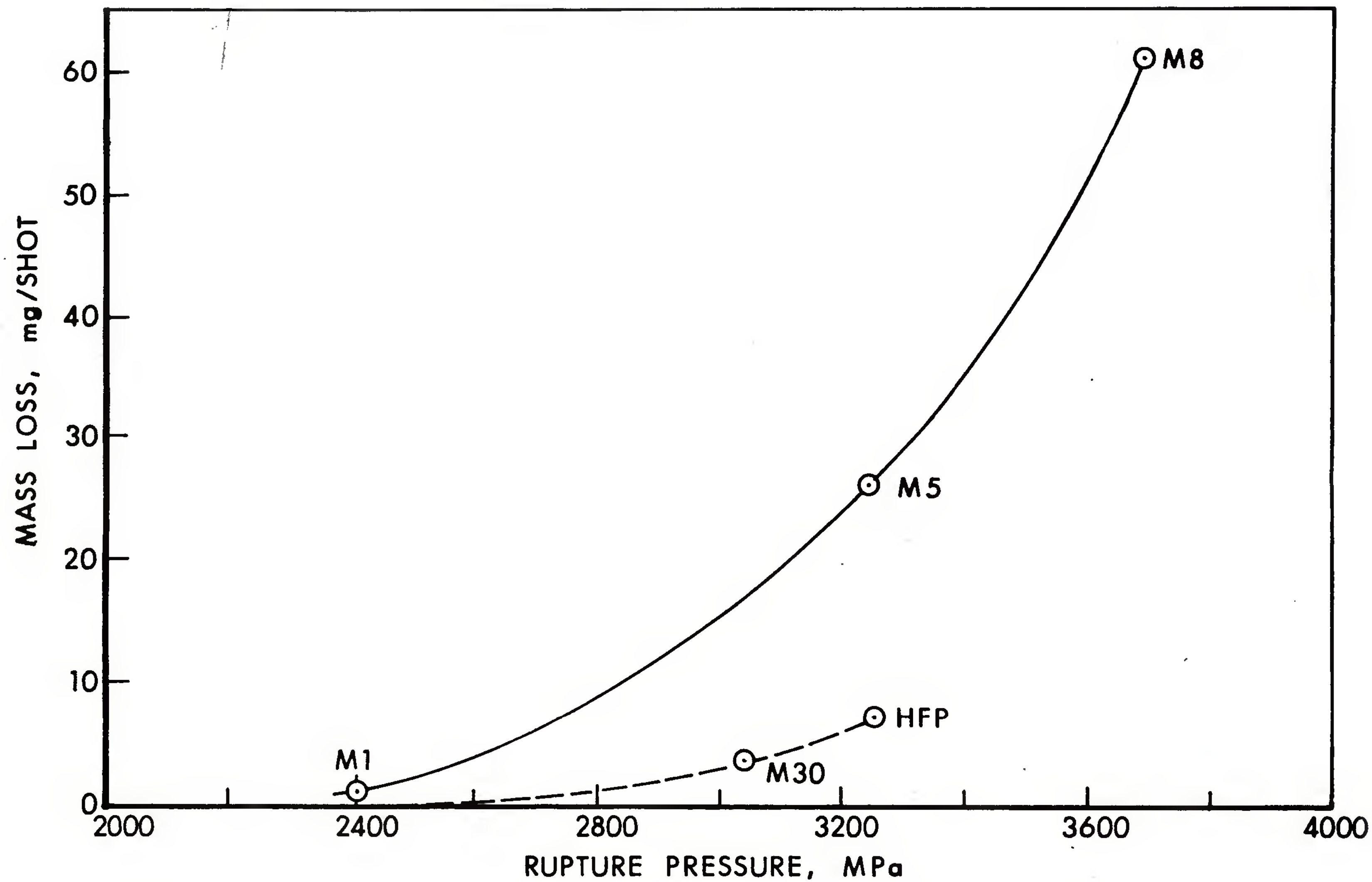


Figure 12. Mass Loss vs Adiabatic Flame Temperature at 283 MPa Rupture Pressure.

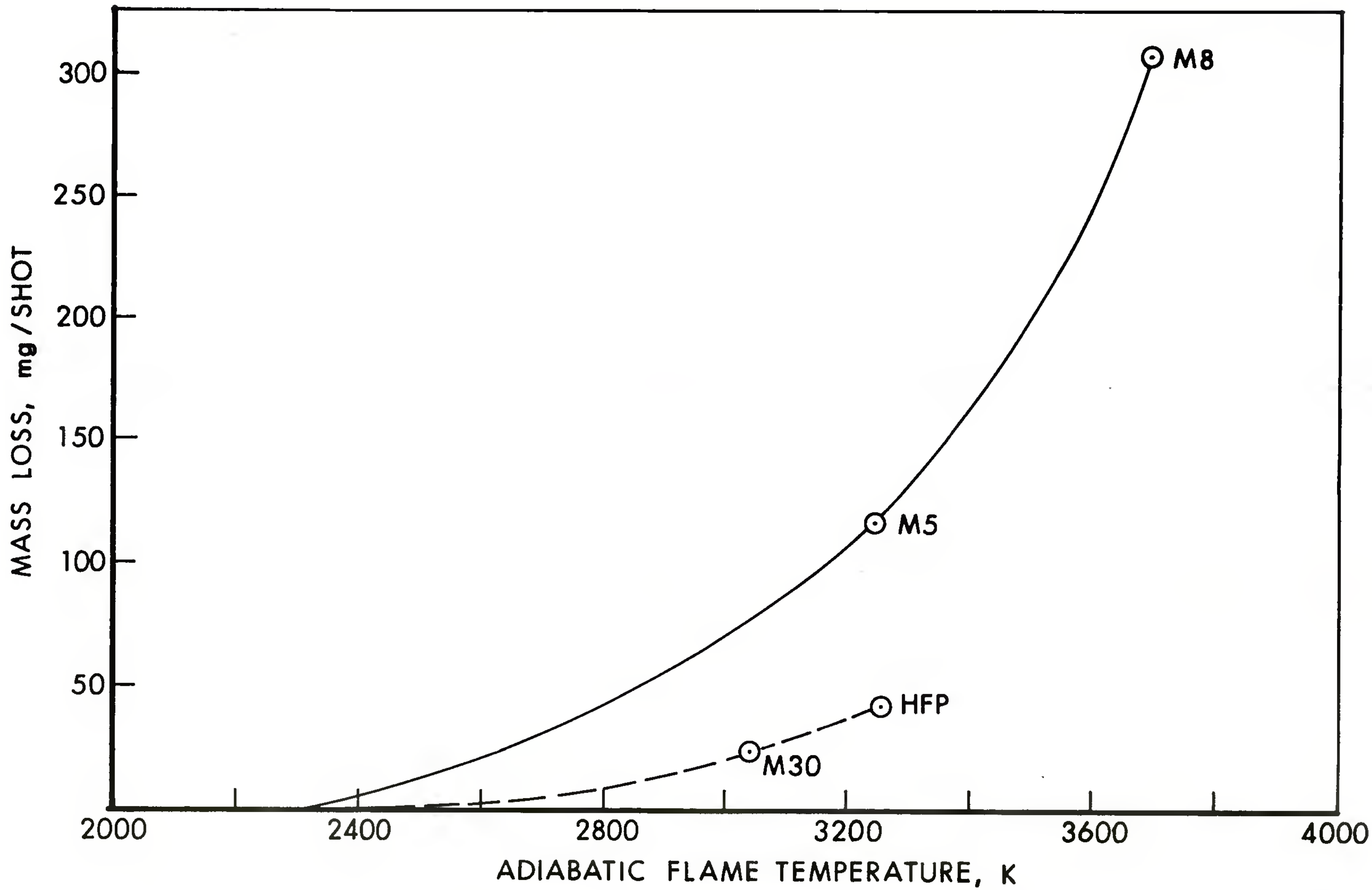


Figure 13. Mass Loss vs Adiabatic Flame Temperature at 413 MPa Rupture Pressure.

It is also evident that the double-base propellants are more erosive than M30 or the nitramine propellants with similar flame temperatures. The difference between the double-base propellant data and the nitramine propellant data is charge mass. The nitramine propellant combustion gases have smaller, average molecular weights; hence, less charge mass is needed to produce a given gas pressure.

This same dependence on charge mass is reflected in Thornhill's[16] semi-empirical equation for estimating the maximum rise in bore surface temperature at the origin of rifling

$$\Theta = \frac{T_o - 300}{1.7 + 0.38d^{0.5} \left(\frac{d^2}{C}\right)^{.86}} , \qquad (1)$$

where

Θ = maximum temperature rise at the bore surface, K,

T_o = adiabatic flame temperature, K

d = diameter, in,

C = charge mass, lb.

Subsequent UK investigators then found that the wear/round, w, was related to Θ by

$$\frac{w}{(d)^{.5}} = ke^{a\Theta} , \qquad (2)$$

where k and a are constants. Frankle and Kruse[17] used Equation (2) to fit wear data for US guns and howitzers and thereby devise an empirical expression for predicting erosion rates of US cannon. One also notes the empirical erosion equation predicts that erosion increases exponentially with adiabatic flame temperature.

IV. CONCLUSION

The erosion behavior of two nitramine propellants with flame temperatures of 2949 and 3255K, respectively, has been shown to be consistent with conventional Army propellants.

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17. *J.M. Frankle and L.R. Kruse, "A Method for Estimating the Service Life of a Gun or Howitzer", BRL Memorandum Report No. 1852, June 1967.* (AD #818348)

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